

## *Science and design: Identical twins?*

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*Recently, Robert Farrell and Cliff Hooker opposed the conventional view that 'design and science are distinct types of intellectual study and production', claiming that science and design 'are not different in kind', and explicitly challenging proponents of the conventional view to 'provide explicit arguments' in its defence. This calls for an in-depth conceptual clarification of the science–design relationship. The aims of the present paper are to take up the gauntlet thrown by Farrell and Hooker, and in so doing, to provide such a clarification. We first analyse Farrell & Hooker's arguments, explaining why we find them unconvincing. We then propose a plausible conception of design versus science, and offer several arguments for considering design and science distinct, albeit related, concepts.*

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It is a commonplace human experience that much self-insight is to be gained by comparing ourselves to others that we come to know well – in particular if they are older and more experienced (parents, older siblings, inspiring teachers, senior colleagues, helpful neighbours, etc.). Likewise, as denizens of the academic community of design and design research, we may have a good deal to learn by understanding in what ways our own young discipline is similar to related but more established disciplines, or differs from them. *Art* is one case in point. *Science* another. Here we focus on the latter.

So, we might wonder, what is the relationship between *design* and *science*, and what can we gain from studying it? Both are forms of intelligent human action of an explorative, problem-solving kind, and as such appear to have much in common. All the same, a successful designer would not necessarily make a good scientist, and vice versa; so it would seem that design and science are different in some respects after all. But for a clear understanding of the relationship between design and science such vaguely conflicting intuitions will not do. Therefore, in this paper we critically examine our conceptions of design and science, and reflect on whether or how we can draw a clear distinction between the two. Arguably, this may facilitate students, practitioners and

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researchers of design in drawing on whatever they deem design-relevant of the considerable body of knowledge and understanding of science that already exists. (For example, there is a well-established philosophy of science, which might inform the philosophy of design, which is only just emerging.) In the long run, as our own discipline and its philosophy gain momentum, a more symmetrical relation of exchange might evolve – much like, over the years, sons and daughters tend to come on an equal footing with their parents.

In the design-theoretical literature it has been taken more or less for granted that design and science are significantly different. In Simon's classic *The Sciences of the Artificial*, which is frequently cited even today, he contends that '[t]he natural sciences are concerned with how things are. [...] Design, on the other hand, is concerned with how things ought to be, with devising artefacts to attain goals' (1996 [1969], p. 114). Buchanan, a prominent contemporary design theorist, once suggested that 'scientists are concerned with understanding the universal properties of what is, while designers are concerned with conceiving and planning a particular that does not yet exist' (1992, p. 17, n. 42). But even before Simon wrote his landmark book and Buchanan drew his line between what is and what is not, Skolimowski (1966) had made a similar statement, though restricting himself to engineering design ('technology'): '[i]n science we *investigate* the reality that is given; in technology we *create* a reality according to our designs' (p. 374). He even condensed this into an elegant dictum: 'science concerns itself with what *is*, technology with what *is to be*' (p. 375).

Rather than taking this conventional science–design distinction for granted, Heylighen, Cavallin, and Bianchin (2009) develop an elaborate argument for it 'from a conceptual and psychological point of view' (*op. cit.* p. 94), drawing on Searle's notion of 'direction of fit' from his philosophy of language, and particularly his philosophy of mind. As they put it, 'the mental activities of a scientist are characterized by a mind-to-world direction of fit' (their beliefs must be true, i.e. their mind must 'match the world'; p. 97). 'In contrast, a designer's mental activities seem to be dominated by a world-to-mind direction of fit' (such activities not aiming at truth, but rather at 'what should be', i.e. at making the world fit the mind; p. 98).

However, in a recent paper, Farrell and Hooker (2012) *oppose* the conventional view that 'design and science are distinct types of intellectual study and production' (p. 481). Based on a sustained analysis of what they see as the core ideas of 'the dominant paradigm in design and design methodology' (p. 484), they reach the remarkable conclusion that 'design and science [...] are most accurately represented, cognitively, as design processes', and that therefore, 'they are not different in kind' (p. 494).<sup>1</sup> It is an undeniable merit of Farrell & Hooker to have so boldly challenged received wisdom about the science–design relationship. But not only do they challenge the

conventional view on the science–design relationship, they also explicitly throw a gauntlet at its proponents, inviting them ‘to provide explicit arguments’ in its defence (p. 493). *A specific aim of this paper is to take up that gauntlet.*

We are not thereby aspiring to settle once and for all the question of whether or not science and design are ‘different in kind’ – as if that were an issue involving only matters of fact. What *is* a matter of fact, however, is that there are people who call themselves ‘designers’ and there are others who call themselves ‘scientists’. Each group of people practices an intellectually demanding profession and may, we assume, benefit from a deeper understanding of what it is doing as compared to what the other group is doing. Furthermore, we believe that a thorough conceptual analysis of design as compared to science, may contribute to the foundations of design research. Therefore, *more generally we aim at a clarification of the relationship between science and design in terms of the differences that set them apart, while acknowledging whatever significant similarities they may have.* We intend our analysis to cover design broadly, ranging from the artistic to the technical design disciplines. Similarly, science is taken to comprise academic research in general, not only (as the word ‘science’ might suggest) the disciplines concerned with the study of natural or technical phenomena.

To achieve these aims, we first summarize in greater detail Farrell & Hooker’s challenge and state the basic assumptions under which we shall address it (*section one*). Next, we critically review their main line of reasoning, and explain why it fails to convince us that ‘design and science are not different in kind’ (*section two*). The rest of the paper is more constructive in nature: we ‘provide explicit arguments’ in response to Farrell & Hooker’s challenge, highlighting in what significant ways science and design differ, and why science – *pace* Farrell & Hooker – is *not* to be thought of as a kind of design (*section three*). Finally (in *section four*), we round off the paper by summarizing the overall picture of the science–design relationship that has emerged from the preceding discussions.

### *1 Challenge and initial assumptions*

The point of departure for Farrell & Hooker’s analysis is what they dub ‘*The Simon-Kroes model of technical artifacts*’ (p. 481, emphasis added). Simon (1996 [1969], pp. 6, 10) conceived of an artefact in terms of a *goal* (purpose), the *inner environment* (physical structure of the artefact), and an *outer environment* (the surroundings) in which the artefact is supposed to achieve the goal by virtue of its inner environment, the structure. On Simon’s view, design (or ‘the sciences of the artificial’ in his terminology), is (are) concerned with shaping the interface between inner and outer environment, ‘attaining goals by adapting the former to the latter’ (Simon, *op. cit.* p. 113). Rather than goal, and the inner and outer environment, Kroes (2002, pp. 294–295)

suggested we speak of *function*, *physical structure*, and *context of human action*, respectively. (A sundial, for example, has the function of keeping time, a physical structure involving a stick casting a shadow, and is used in the context of human action of ordering events; *op. cit.* p. 295, Figure 3.) An artefact cannot have a goal, but it can have a function. More importantly, the modification clearly brings out an idea that was only implicitly present in Simon: *the dual nature of artefacts*. On the one hand a technical artefact is a *physical* object and can be understood as such by studying its physical structure. On the other hand it is an *intentional* object in that it fulfils its function in its context of human action. Bringing this duality into focus is important, because ‘we cannot make sense of technical artefacts without taking into consideration their physical structure, but also not without their context of intentional human action’ (p. 296). To understand the relation between the intentional and the physical aspect of artefacts is essential to understanding design and design methodology, but it is to some extent still an open question how designers are able to bridge the gap between a functional description of an artefact (to be employed in a given context of human action) and the structural description that is a prerequisite for producing such an artefact (*op. cit.* pp. 298 f.; see also (Kroes, 2012)).

According to Farrell and Hooker (2012, p. 484), it is ‘this Simon–Kroes model of the nature of technical artefacts that lies at the core of the dominant paradigm in design and design methodology’, and they proceed to show that if this model is accepted, then one also has to accept that the products of science (‘those things that scientists produce’) are just as much ‘technical artefacts’ as are the products of design; hence that an argument for the conventional distinction between science and design cannot be based on a premise to the effect that the two disciplines produce fundamentally different things. Rather, they develop a conception of design so broad as to subsume science: ‘both of them are most accurately represented, cognitively, as design processes’ (as quoted above). And this is what brings them to their final conclusion: ‘both design and science use design processes and reasoning strategies to produce artificial objects, therefore, *they are not different in kind*’ (p. 494, emphasis added). For convenience of exposition, we shall refer to their claim that science and design ‘are not different in kind’ (or, as they put it on p. 487, ‘the conclusion that science and design are not in principle distinct’) as *Farrell & Hooker’s thesis of unification*.

In alignment with this unconventional view, Farrell & Hooker challenge ‘those who still want to distinguish design and science’ to ‘show a plausible conception [of design] that does not include science’ (p. 490).<sup>2</sup> In their concluding section, they repeat the challenge in the form of a dilemma (p. 493):

‘Modern defenders of the Simon–Kroes model of technical artifacts will either have to accept the consequences that we have drawn out from the

model [i.e., that theories etc. produced by science are just as much (technical) artefacts in the sense of the model as are the products of design in general], or they will have to provide explicit arguments as to why the cognitive processes of science and design are not equally best characterised as design processes.’

We, for our part, do not see ourselves here as defenders (modern or otherwise) of the Simon–Kroes model, and we have no qualms accepting the consequence that Farrell & Hooker draw from that model: that the products of science are artefacts; e.g. ‘theories set out in journal articles’ (*op. cit.* p. 484). Yet we are not convinced that Farrell & Hooker’s analysis of the model, and the arguments they offer, justify their much more far-reaching conclusion, the unification thesis that design and science ‘are not different in kind’. So if, in the face of the above dilemma, we were forced to choose between *either* acknowledging science as a special case of design (‘not different in kind’ from it), *or* providing ‘explicit arguments’ to the contrary, we would opt for the latter without hesitation.

Even though our mission is not to defend the Simon–Kroes model (and consequently we may not be in the intended target group of Farrell & Hooker’s challenging dilemma), we must admit our allegiance with ‘those who still want to distinguish design and science’. And to atone for whatever habitual thinking on our part this confession may imply – and more importantly, to clarify the distinction at issue – we will indeed attempt to ‘show a plausible conception [of design] that does not include science’, and in so doing, ‘provide explicit arguments’ for it, thus after all taking up the gauntlet thrown by Farrell and Hooker. Not because we have any particular wish to prove them wrong, or to defend the conventional view at all costs, but rather to examine and critically compare various arguments in favour of the two opposed positions, and to bring to light the conceptions of science and design on which such arguments must inevitably rest.

However, before we embark on this endeavour, let us briefly state some basic assumptions and observations from which we shall proceed:

### *1.1 On abstractness and artefacts*

Farrell and Hooker (2012, p. 485) ask ‘what good reason is there to exclude abstract things from being artifacts?’, implying that there are none. If ‘abstract’ were taken to mean ‘nonspatiotemporal’, i.e., existing outside time and space (Lowe, 1995, p. 513 f.), or ‘causally inefficacious’, i.e., failing to produce the desired effect (Rosen, 2012, Section 3.2), then presumably abstract things would be either eternal and immutable, or useless *by definition*, respectively, which seems a fairly good reason within the present context for excluding them from being artefacts. But there are other definitions of ‘abstract’, and it is not our intention to quibble about this point.

We will simply grant Farrell & Hooker that artefacts can indeed be abstract – or at the very least non-material. Thus, for the purposes of the present discussion, artefacts *may* be material entities such as shoes and fuel pumps and dinner plates; but (following Buchanan (1998), Buchanan (2001), Buchanan (2004), and Krippendorff (2007)) may also be non-material (and arguably abstract) entities, such as services, interfaces, organizations, scientific theories, and software. We see no reason for restricting the scope of our discussion to *technical* artefacts either, as did Kroes (who was writing in a context of engineering design).

### 1.2 On artificiality and artefacts

Throughout their paper, Farrell & Hooker keep returning to the notion of artificiality and artefacts, and the pros and cons of distinguishing science from design in terms of artificiality of their products, or even artificiality of science and design themselves. We have no substantial objections to Farrell & Hooker's use of the notions of (technical) artefact and the artificial *per se*. However, two remarks are in order here, to make our view on the matter clear from the outset.

*First*, Farrell & Hooker state that, on the assumption of the Simon-Kroes model, 'all the sciences also produce artificial things' (p. 481). Whether that is indeed the case depends on how the notion of artificial things (artefacts) is interpreted. If an artefact is a human-made physical object that performs its function on the basis of its physical structure, then there is reason to question this claim. Natural history is a branch of science, but did it produce artefacts in this sense? If the notion of artefact is taken to include (abstract) symbolic artefacts that fulfil cognitive functions, then it seems safe to claim that all sciences produce such artefacts; in that case, also the classification schemes of natural history are artefacts. We concur with Farrell & Hooker in that broader conception of artefacts.

*Second*, following Simon, Farrell & Hooker use at least two different notions of artefact (artificial). On the one hand, artefacts (artificial things) are taken to be whatever is 'synthesized [...] by man' (p. 481), or 'constructed by human beings' (p. 484); on the other hand artefacts are also conceived of as 'meeting points' between inner and outer environments (pp. 482, 486, 487). For Simon this means that the human organism becomes 'the very prototype of the artificial' (p. 489). Farrell & Hooker reject this idea if it is meant as a fundamental distinction between the natural and the artificial. But they follow Simon in this claim if 'artificial' is construed 'as a convenient short-hand for the great variety of natural adaptive behaviour' (p. 489). From this they conclude that all intelligent adaptive behaviour is artificial, including science and design. But why is a great variety of *natural* adaptive behaviour artificial? And if our general capacity for intelligent adaptive behaviour is the result of our evolutionary past, i.e. of our natural evolution (as Farrell & Hooker seem to contend a few lines further on), why then is it artificial? Surely it is not artificial in the sense that it

is synthesized by man or human-made. — Here two different distinctions between the natural and the artificial are run together, which makes it difficult to understand what Farrell & Hooker mean when, for instance, they write ‘...if all intelligent adaptive behaviour is artificial, then both design and science are artificial because they are both examples of the process of, and the product of, intelligent adaptive behaviour’ (p. 489). It is not clear to us whether this implies that the products of science and design are artificial in the sense of ‘synthesized by man’.

To avoid any such ambiguity about artificiality in our discussion of Farrell & Hooker’s thesis of unification, we will be using the notion of artefact as defined by Hilpinen: ‘An artifact may be defined as an object that has been intentionally made or produced for a certain purpose’ (2011). On our interpretation, such artefacts may include *non-material* entities, such as pieces of music and organizations, but not *mental* states, such as ideas (more on this in Section 3.2). This comes close to but is more precise than Simon’s idea of artificial things as synthesized by humans.

### *1.3 On design and science as kinds of action*

In order to be clear about what is at issue in the following it is important to distinguish carefully between science and design as socially institutionalized disciplines and scientists and designers as socially institutionalized practitioners (professionals) of those disciplines on the one hand, and science and design as kinds of intelligent human actions and the products that are the outcome of those actions on the other. There is no one-to-one correspondence between these two: scientists and designers as practitioners of these socially institutionalized disciplines may perform either kind of intelligent human action and may make use of the outcomes of those actions. For the present purposes, we think of design (designers) and science (scientists) *not* as social phenomena but as *kinds of intelligent action (agents performing these kinds of intelligent action)*.<sup>3</sup> This means that somebody who performs an action that is an instance of the kind of intelligent action called ‘science’ is by definition a scientist, and the same applies *mutatis mutandis* for a designer. It also means that when somebody performs actions of both kinds (s)he is acting as a scientist and as a designer (see the caveat on the co-occurrence of design and science below).

So, when Farrell & Hooker occasionally speak of design and science as ‘disciplines’ (pp. 480, 489), we take it to mean kinds of intelligent action, and these kinds of action, and their products, are what this paper is about; not their concomitant social phenomena. Indeed, we wholeheartedly agree with Farrell & Hooker when they say that ‘both design and science are manifestations of the general human capacity for *intelligent action*’ (*op. cit.* p. 487; emphasis added). What separates our view from theirs is that we see design and science as kinds of intelligent action that *differ* in important ways, as we shall argue in Section 3. Whereas Farrell & Hooker look at science and design primarily from a cognitive

perspective, and appear to assume that design just as science is primarily a kind of cognitive action, we will argue that design is not primarily a kind of cognitive action, although design, qua intelligent action, does involve cognitive action.

#### *1.4 A caveat on co-occurrence of design and science*

In debating whether or not design and science are of the same nature, it is important to note that specific *instances* of the action kinds we call ‘design’ and ‘science’ often *co-occur*. But that does not entail that they, nor the kinds of which they are instances, are similar in nature. Specific acts of, say, talking and listening often co-occur, as do acts of cooking and washing hands, of giving and taking. Yet no one would claim for that reason that talking is a kind of listening, that washing hands is a kind of cooking, or that taking is a kind of giving. There may be good reasons for claiming that two kinds of action are similar, or that one is a special case of the other, but co-occurrence is not one of them.

Even if the occurrence of one kind of action is conditional on the occurrence of another kind, it does not follow that the two kinds of action are the same. For example, consider experimental research to detect elementary particles: CERN’s recent experiments to detect the Higgs boson are a major project of science if ever there was one. Higgs bosons cannot be observed without appropriate measurement equipment and since these bosons do not occur naturally on Earth they have to be ‘produced’. For those reasons CERN’s experiments involve the massive design of (measurement) equipment. From this it does not follow that there is no difference between performing the experiments (doing scientific research) and designing and making the necessary equipment. So, let us not be confused by the fact that sometimes or perhaps always instances of science and design co-occur.<sup>4</sup>

Now the question may be raised whether there are ‘pure’ forms of science and design, with no co-occurrence of the other kind of action. The observation and reporting of a remarkable fact, for instance of a solar eclipse, may come closest to a ‘designless’ form of science (albeit primitive); no artefact is made, except the observation report itself, and that hardly involves design. Conversely, designing a new piece of clothing may be done without performing any interesting form of scientific research or producing any interesting scientific results.

Clearly, however, in modern day scientific and (technical) design practice, science and design go hand in hand. In what follows, we shall assume that these mixed forms of science and design can be understood to a large extent as the co-occurrence of two different kinds of action, one known as science, the other as design.

## *2 A critique of Farrell & Hooker’s thesis of unification*

In arguing for their unification thesis, Farrell & Hooker use two kinds of arguments. There are *negative* arguments by which they reject potential reasons



for distinguishing science from design. And there are *positive* arguments by which they seek to convince us that certain similarities between science and design are strong enough to justify their conceptual unification. Below, we review these two groups of arguments, though not all of them in detail. Rather we will discuss what we consider representative examples in sufficient detail to explain why we are not persuaded by either kind of argument that Farrell & Hooker's unification thesis is tenable.

### 2.1 Negative arguments – against distinguishing science and design

Having reviewed the 'Simon-Kroes model of technical artefacts', Farrell & Hooker move on to present their negative arguments (*op. cit.* Section 2). The most prominent of these consists of the rejection of a traditional argument why design and science are different. This distinction argument focuses on the kind of outcome produced by design and science and may be summarized as shown in Table 1, in which we inserted literal quotations from Farrell & Hooker's own summary of the distinction argument (pp. 480 f.).

However, the disciplines (kinds of intelligent action) under scrutiny are science and design, and since we can safely assume that both are disciplines of 'intellectual study and production', there is no need to add that qualification in the conclusion, or anywhere else in the argument. As for the second premise, Farrell & Hooker themselves use the phrase 'metaphysically distinct types of things' (p. 481) as a stylistic variant of the phrase 'different metaphysical things'. We consider this variant to convey the same meaning as the phrase in Table 1, but since the variant phrase is more precise, we shall adopt it. Thus we arrive at the revised formulation of the distinction argument shown in Table 2, which we will take as a point of departure for our critique of Farrell & Hooker's negative arguments. The reformulation is for initial clarification only; it does not in itself constitute a critique of anything that Farrell & Hooker say.

**Table 1** The traditional distinction argument<sup>a</sup> summarized and rejected by F & H on pp. 480 f

Claim no.	Claim (literal quotation from Farrell & Hooker)	Justification
1	If disciplines produce different metaphysical things <sup>b</sup> then the intellectual study and production of those things will be significantly different	Premise
2	Design and science produce different metaphysical things	Premise (false, F & H argue)
3	Design and science are distinct types of intellectual study and production	From claims 1 and 2

<sup>a</sup> We use 'the traditional distinction argument' as a name, because Farrell & Hooker present it as an example of what in their abstract they call 'a long tradition of arguing that design and science are importantly different'.

<sup>b</sup> Summarizing their discussion on page 494 of their paper, Farrell & Hooker repeat the argument using 'objects' instead of 'things'. Apparently they do not ascribe any difference in meaning to this variation; neither do we. (On use of 'metaphysical', see note in Table 2.)

**Table 2 Edited version of the traditional distinction argument opposed by F & H**

<i>Claim no.</i>	<i>Claim</i>	<i>Justification</i>
1	If two disciplines produce metaphysically <sup>a</sup> distinct types of things then those disciplines are significantly different	Premise
2	Design and science produce metaphysically distinct types of things	Premise
3	Design and science are significantly different	From claims 1 and 2

<sup>a</sup> In this context, ‘metaphysically’ can be read as ‘fundamentally’, or ‘ontologically’. Ontology is the study or theory of being and fundamental categories of what is (e.g., abstract and concrete entities, events etc.). Metaphysics, a rather heterogeneous branch of philosophy, includes ontology among its subjects.

Farrell & Hooker argue that the second premise of the traditional distinction argument is false, because both design and science produce the same kind of things, namely artefacts. And therefore, they conclude, the argument for the distinction between design and science does not stand. Of course, from the falsity of the second premise it does not follow that the conclusion of the argument is false; i.e. that Farrell & Hooker’s thesis of unification is true. That would clearly be a *non sequitur*. Nevertheless Farrell and Hooker appear to draw this conclusion from the first sections of their paper, since they open Section 3 with the following remark: ‘The *conclusion that science and design are not in principle distinct* is reinforced when we consider the nature of intelligence’ (p. 487, emphasis added). We have already stated (in Section 1 above) that we have no qualms accepting that both design and science produce artefacts. The inference that Farrell & Hooker draw from that observation to the negation of premise 2 in the distinction argument may be disputable (as we shall argue later, in Section 3.5), but let us assume for the moment that Farrell & Hooker are justified in drawing that inference. Even then the question remains: *what, if anything, justifies them in considering their unification thesis a ‘conclusion’* in the passage just quoted? To answer that question, let us examine their negative arguments a little closer.

Adopting a definition of artefacts inspired by Simon (whatever is ‘constructed by human beings to realise a function’; p. 484) and virtually identical to Hilpinen’s that we cited earlier, Farrell & Hooker point out that ‘the whole of science through and through is artificial, since every part of it has been constructed by humans to contribute to fulfilling the purpose of understanding our world’. This is apparently taken as evidence against the truth of premise no. 2 of the traditional distinction argument (Table 2), in that it is taken for granted that the products of design are artefacts in the same sense. The contention that *the products of science are artefacts, just as are the products of design*, seems to be pivotal in Farrell & Hooker’s argumentation, and the next couple of pages (pp. 485–486), they spend on carefully defending it against two different objections that they imagine proponents of the traditional distinction argument might come up with. Both of these objections revolve around the

contrast between what is natural and what is artificial. However, since we agree with Farrell & Hooker that both science and design produce artefacts (in Hilpinen's sense), and since none of the objections against that contention were made or endorsed by us, we see no need to criticize the further negative arguments constituted by Farrell & Hooker's defence against those objections. Suffice it to note here that even the most careful defence of the contention that the products of science as well as design are artefacts, achieves nothing by way of supporting Farrell & Hooker's thesis of unification. At most, it may be taken to show that the second premise of the traditional distinction argument in Table 2 is false, but *that*, as already noted, does not entail the negation of the conclusion to that argument – i.e., the thesis of unification. It is therefore misleading when, in the opening sentence of Section 3, Farrell & Hooker refer to their thesis of unification as a 'conclusion'. Up to that point, no valid argument has been offered to support it as such.

However, at the very end of their Section 2 Farrell & Hooker suggest an interesting negative argument (almost as an afterthought, and slightly out of context, since it does not contribute to defending the pivotal claim at issue, namely that the products of science are artefacts). This negative argument is remarkable because it is *not* directed against the traditional distinction argument in Table 2. It begins as follows: 'Nor can an opposition [i.e., distinction] between [science as] *studying existing things* unaltered and [design as] *producing novel things* be sustained ...' (p. 487, emphasis added). Here two new distinction arguments are implicitly presupposed: one asserting that science can be distinguished from design in terms of their *purpose* (studying, vs. producing), and one distinguishing them in terms of their *subject matter* (existing things vs. novel things). The negative argument continues, '... since science constantly produces both novel abstract artifacts such as new concepts and theories, and new physical artifacts such as new instruments, new technical procedures and so on.'

As for the instruments and technical procedures, let us dismiss them for simplicity as the fruits of co-occurring acts of design (and subsequent acts of production, or implementation) in a scientific context. But we admit that science produces novel concepts and theories, and that these may be construed as artefacts, as abstract tools with a cognitive function (with the possible exception of concepts, if they are considered a kind of ideas or are otherwise classified as mental states). Still, we submit, producing those concepts and theories is not the (primary) *purpose* of science, which is rather, in Farrell & Hooker's own words, 'the purpose of understanding our world' (p. 484). That is, the (primary) purpose of science is to understand, or to study, our world – as opposed to design whose (primary) purpose is neither to understand nor to study anything (although such activities may co-occur with design). That is the reason why we object to treating design as being primarily a kind of cognitive action (Section 1.3). So the negative argument under scrutiny does not

convincingly preclude a distinction of science from design by *purpose*. And it does nothing at all to rule out a distinction by *subject matter*, for even though Farrell & Hooker are right that the concepts and theories produced by science are novel (just as the products of design), the concepts and theories produced by science do not constitute its subject matter. We can still maintain that the subject matter of science is ‘existing things’, while the subject matter of design is ‘novel things’. Or to put it perhaps more aptly (repeating the Skolimowski-dictum from our introduction), we can still maintain that ‘science concerns itself with what *is*, technology [i.e. design] with what *is to be*’. (We consider distinction arguments more directly in Section 3.)

In conclusion, then, the last negative argument offered by Farrell & Hooker does not succeed in defeating any of the two distinction arguments against which it is implicitly directed. And even if it *had* so succeeded, other distinction arguments might still remain unaffected. So, like the other negative argument(s) of Farrell & Hooker’s, this one does not constitute a valid argument for their thesis of unification of science and design.

## 2.2 Positive arguments – stressing similarities of science and design

Let us proceed to the positive arguments by Farrell & Hooker. In Section 3 of their paper, they produce various arguments in support of their thesis of unification; arguments allegedly ‘reinforcing the conclusion’ that ‘science and design are not in principle distinct’ (p. 487).

In a rather difficult passage (we noted its difficulty in Section 1.2), they entertain the idea that both science and design themselves, as kinds of cognitive action, are ‘artificial’ (*op. cit.* p. 489). Whatever they may mean by ‘artificial’ here, appealing to this idea as such does little or nothing to support their unification thesis. Like the other positive arguments, whatever cogency this one may have, depends on how *relevant* the fact that both science and design share a certain feature is for characterizing them as ‘not in principle distinct’. But no matter what features they may share, the obvious possibility remains that there could be other features in terms of which science and design significantly *differ*.

In the same vein, Farrell & Hooker also argue that science and design are similar because our intelligent capacity for problem solving is an evolutionary outcome, and evolution has not selected ‘specific scientific cognitive capacities’, such as constitutive reasoning strategies (i.e. reasoning in relation to Simon’s ‘inner environment’ of artefacts), versus ‘specific design cognitive capacities’, such as functional reasoning strategies (in relation to the ‘outer environment’) (p. 489). Design and science alike, they claim, make use of both reasoning strategies.

They furthermore consider some prominent definitions of design that bring to the fore the general capacity for intelligent problem solving. For example, they quote Willem's definition of design as 'the intentional development of anything ... [where] a plan or prototype for something new is devised' (pp. 489 f), and assert that such creative problem solving characterizes science just as well, 'especially in new physical domains where existing methods and instruments cannot be presumed to work'. However, such intentional development of novel methods or instruments for scientific research is an example of what we would characterize as acts of *design* that *co-occur* with acts of scientific research, without therefore themselves *being* acts of such research (Sections 1.3 and 1.4).

Farrell & Hooker draw on Simon's often-cited definition of design, too: 'Everyone designs who devises courses of action aimed at changing existing situations into preferred ones' (p. 490). They point out that according to this definition scientists are designers since they devise courses of action to change their state of knowledge. Changing existing situations into preferred ones involves problem solving and to do this in an intelligent way involves '[e]rror/misfit discovery and avoidance, enhanced by opportunistic improvement' (p. 493). This intelligent problem solving capacity is part and parcel of science and design. In this respect they are not different in kind.

Planning and inventing are further features shared by both science and design (p. 490), as are synthesis, decision-making, creativity, 'searching through large sets of possibilities' (p. 491); learning from failures or errors, and 'opportunistic improvement' (pp. 492 f.).

These positive arguments all appeal to the fact that both science and design employ the same overarching capacity for intelligent problem solving. In the conclusion of Farrell & Hooker's paper this is summarized in the following way:

'Moreover, since both design and science are products of the general capacity for intelligent action that characterises human intelligence, both of them are most accurately represented, cognitively, as design processes. In sum, both design and science use design processes and reasoning strategies to produce artificial objects, therefore, they are not different in kind' (p. 494).

Our main problem with all these positive arguments offered by Farrell & Hooker is the level of analysis and the conceptions of design they have chosen to defend their thesis of unification. These are chosen in such a general way that any form of intelligent problem solving in whatever context or practice, including science, is a form of designing.

For example, it may be true that this general capacity for intelligent problem solving is the outcome of evolution (*op. cit.*, p. 489), but what does that tell us about more specific forms of intelligent problem solving in different practices?

Suppose that you want to learn to play the piano and you devise a course of action to do so: you plan to take piano lessons and to practice daily for one hour. This planning falls squarely under Simon's definition of designing. But what does this form of designing tell us about the specific physical and mental skills that you have to develop in order to be able to play the piano? Of course, when you start learning to play the piano you will run into problems, reading and understanding the score of a piece of music, and then again you will devise courses of action to solve those problems. So, in turn you will be designing, all the way down to the lowest level of activity, for instance, you will devise a course of action to learn coordinate the movements of the fingers of your right hand. Does this form of designing exhaust all the intelligent forms of problem solving that play a role in learning to play the piano, in solving scientific problems or engineering design problems, or in solving whatever problem in whatever practice? Does this mean that the only intelligent capacity that we have to master in all these various fields is '[e]rror/misfit discovery and avoidance, enhanced by opportunistic improvement' (p. 493)?

Apparently Farrell & Hooker are aware that there may be differences between science and design, but they play down their significance; as they say, there may be

'difference in norms between science, dominated by epistemic norms, and design, dominated by practical norms, and related differences, e.g. with respect to patents in science and design. Our contention is that i) the differences are not as large as may be thought (each must also make some use of the other's norms) and ii) whatever differences there are do not affect our conclusion here that, in respect of its underlying process (methods) and its kinds of products, no difference has been made out between science and design' (p.490).

As regards the last point, it would indeed be strange if these other differences would affect or invalidate the underlying process or method of learning from errors; learning from errors appears to be a basic norm of rational behaviour underlying any practice of intelligent or rational problem solving. In our view, the differences in intelligent problem solving in science and design are more important than Farrell & Hooker suggest. If indeed a good scientist does not make a good designer and vice versa, then there is reason to assume that from a methodological point of view the skills and competencies that scientists and designers make use of in intelligent problem solving are different.<sup>5</sup> The principle of learning by trial and error is simply too coarse-grained a criterion to bring these relevant differences into sight. There is more to be said about design methodology than that it makes use of an evolutionarily developed general capacity for intelligent problem solving.

To sum up, what Farrell & Hooker's positive arguments do in order to 'reinforce' their 'conclusion that science and design are not in principle distinct'

(pp. 487 ff.) is to explore a number of similarities between science and design, as briefly reviewed above. However, if by ‘not in principle distinct’ they mean ‘identical’ or ‘indiscernible’ (and what else could they mean?) it is hard to see how their thesis of unification could have been ‘reinforced’ by any of this — unless one assumes that identity follows from similarity, or that indiscernibility does. We will not accuse Farrell & Hooker of tacitly relying on an assumption so patently false; but if they don’t, what is the relevance of the various similarities they adduce, with respect to their unification thesis that ‘science and design are not in principle distinct’? Certainly ‘reinforcing the conclusion’ cannot mean *proving* that thesis (in the sense of providing a valid argument with plausible premises, and with the thesis as a conclusion). What Farrell & Hooker achieve by way of reinforcement is at most to point out a variety of ways in which their thesis cannot be strictly *disproved*. — However, by our critical remarks regarding the *thesis of unification* and Farrell & Hooker’s *arguments* for it, we do not mean to deny that the science–design *similarities* that they point out may be *interesting* in their own right.

### 3 Differences between science and design

It is time to strike a more constructive note, and, rising to Farrell & Hooker’s challenge, attempt to ‘show a plausible conception [of design] that does not include science’, and provide ‘explicit arguments’ for it, as promised in Section 1. To do so, we first consider the highly polysemous *word* ‘design’ and cognate expressions, describing how precisely we shall use them for our theoretical purposes (Section 3.1). As we shall argue next, the conception of design thereby captured is plausible (Section 3.2), but even if we define ‘science’ in close analogy to ‘design’ (as in Section 3.3), design and science do not coincide (Section 3.4). For good measure, we go on to offer a defence of premise 2 of the traditional distinction argument (Section 3.5), and finally (in Section 3.6) briefly address the issue of whether there are methodological differences between science and design.

#### 3.1 The word ‘design’ and other key terms

In ordinary parlance, the word ‘design’ appears both as a verb and as a noun, each with a surprising number of different meanings and usages, as any good and comprehensive dictionary of contemporary English will show. However, for the theoretical purpose of the present discussion, picking a ready-made dictionary definition of ‘design’ will not do. Modern dictionaries are based on ‘large collections of naturally occurring spoken and written texts, so-called corpora’ (Mondorf, 2009). They are made to support the understanding or production of utterances in natural language; but *not* as results of, or tools for, rigorous conceptual analysis. Yet for such analysis to be *plausible*, it must not only achieve conceptual clarity and precision, but also express it in words borrowed from ordinary parlance, without violating (too much) everyday linguistic practice. Thus defining ‘design’, for example, in a theoretically satisfactory yet plausible way is far from trivial; and this may go some

way to explain why no manifest consensus has emerged among design researchers about such a definition.

The best we can do to conduct a serious discussion on design versus science, is to be fairly explicit about the way in which we use our key terms. As for the case in point, we begin by putting forward the following definition, which assigns a meaning to the uncountable noun ‘design’, and does so in a way, we contend, that is both compatible with ordinary parlance (i.e. ‘plausible’) and precise enough for us to argue that *design* conceived as a kind of intelligent action ‘does not include science’:

‘*Design*’ (noun, uncountable): the kind of intelligent action that consists of proposing a novel idea for an artefact, so as to enable yourself or others to make one or more artefacts according to that idea. (The idea is to be *novel* in the sense that it is not the result of copying an already existing idea.<sup>6</sup>)

For example, this uncountable noun appears in the sentence: ‘Design is considered a so-called fine art, and is taught as such; but it actually pervades much of everyday life.’ It is at the very focal point of our dispute with Farrell & Hooker, who frequently use it in connection with ‘science’, also an uncountable noun (to be similarly defined in Section 3.3).

In the definition, the phrase ‘to *make* one or more artefacts’ reflects Hilpinen’s definition of ‘artefact’ as ‘an object [...] intentionally *made* or produced for a certain purpose’ (emphasis added to both quotes). Prima facie, to ‘make’ in these contexts might carry a connotation of something material, as in ‘let me make you a nice cup of tea’, or ‘the housing is made of die-cast aluminium’. However, ‘make’ is to be taken in a broader sense, meaning ‘produce’, ‘establish’, or ‘bring into existence’, etc. As noted in Section 1.2, we take Hilpinen’s definition of ‘artefact’ to cover not only material entities, but also non-material ones, such as music or organizations. Our definition of ‘design’ inherits its broad scope from that of Hilpinen’s definition of ‘artefact’.

The noun ‘design’ has a *countable* version, too, with a rather different meaning, as illustrated (twice) by the following example: ‘Utzon’s design for the Sydney Opera was a spectacular project, but he also made several interesting designs for modestly sized private houses.’ However, to minimize potential confusion we eschew this countable version altogether. Instead we shall use the expression ‘*artefact proposal*’ (another more self-explanatory term for what is called ‘design representation’ in Galle, 1999) by which we refer to whatever sketches, descriptions, shop drawings etc. that manifest themselves as blueprints, CAD models or otherwise, as an immediate result of someone performing an act of design (i.e., as a result of the agent ‘proposing a novel idea for an artefact’).

But terminological caution should not be allowed to force circumlocutions such as ‘performing an act of design’ upon us. Therefore we cannot forswear



the use of the *verb* ‘(to) design’. It, too, comes in two versions: The *intransitive verb* ‘design’ may be defined either in terms of, or in exact analogy to, the uncountable noun: ‘To *design*’ (verb, intransitive): to perform an act of design; or (in other words), to propose a novel idea for an artefact, so as to enable ... (etc.).<sup>7</sup> As for the *transitive verb* ‘(to) design (something)’, as in ‘Utzon designed the Sydney Opera’: Once an artefact has been made according to an idea expressed through an artefact proposal, we can convey this fact by saying that the artefact was designed by the agent who made the artefact proposal – or, in the active voice: that the agent designed the artefact in question.

The noun ‘*designer*’ is comparatively unproblematic. Keeping in mind the distinction between the notion of designer as a socially institutionalized practitioner and as somebody performing a particular kind of intelligent human action, and given the above definition of the intransitive verb, we can describe its meaning quite simply as: a person (or other agent) who performs an act of design. Finally, we reserve the expression ‘*designed artefact*’ for referring to an artefact that some agent has designed.

### 3.2 *A plausible conception of design*

The conception of design captured by the system of definitions above is *plausible*, we contend, in that it does not radically depart from common parlance as recorded in a contemporary corpus-based dictionary. For example, according to one such dictionary, the first of seven meanings of the uncountable noun ‘design’ is ‘the art or process of making a drawing of something to show how you will make it or what it will look like’ ([Longman Dictionary of Contemporary English](#)),<sup>8</sup> of which our definition in Section 3.1 may be considered a variant. It is more specific in some respects (‘artefact’ rather than ‘something’; some degree of novelty required), and more general in others (e.g., no mention is made of a ‘drawing’ as the means of expression). Similar remarks apply to the other key terms we defined.

Furthermore, our conception of design is plausible because it accords reasonably well with definitions and analyses in the design-theoretical literature. For example, our definition of the uncountable noun was developed as a refinement of ‘Creatively proposing an idea, so as to enable yourself or others to make an artifact according to the idea’ ([Galle, 2011](#), p. 93). Conceptually, if not stylistically, there is also a conspicuous similarity to Bamford’s more formal definition of the intransitive verb ‘(to) design’:

‘Someone, *S*, designs or formulates a design [what we called an “artefact proposal”] for some logically possible thing, *A* (or type of thing,  $T_A$ ) at some time, *t*, just when, (1) *S* imagines or describes *A* (or  $T_A$ ) at *t*; (2) *S* supposes in (1) that *A* (or some token of  $T_A$ ) would be such as to at least partially satisfy some set of requirements, *R*, for *A* (or  $T_A$ ) under some set of conditions, *C*; (3) The partial satisfaction of *R* that *S* supposes in (2) is a

problem for which ... (4) ... the solution candidate [that] *S* imagines or describes in (1) is novel for *S* at *t*.' (Bamford, 1990, p. 234).

Note that here, *A* ( $T_A$ ) is an artefact (type) in Hilpinen's sense,<sup>9</sup> because by conditions (2) and (3) it is, in Hilpinen's words, 'an object that has been intentionally made or produced for a certain purpose': namely to satisfy (partially) the requirements *R* under conditions *C*. Our definition implicitly covers the notion of artefact *type* that Bamford mentions, because according to our definition, some agent is *enabled* 'to make one or more artefacts' according to the designer's idea. In other words, according to that idea, zero, one or more artefacts may be made, and so the idea plays the role of a type.<sup>10</sup> Bamford's definition leaves implicit that the purpose of imagining or describing the 'logically possible thing, *A* (or type of thing,  $T_A$ )' is to enable someone to make *A* (or an instance of  $T_A$ ). In this respect our definition is more elaborate than Bamford's. The apparent simplicity of our definition, as compared to Bamford's, is due to the fact that much of the complexity introduced by his conditions (2) and (3) is avoided in our definition by reference to the concept of artefact, for which Hilpinen has already provided the analysis. Thus it seems fair to say that all in all our conception of design covers much of the same ground as Bamford's and vice versa. Furthermore, both of these could be considered simplifications of the very elaborate 'reconstruction of product designing' by Houkes and Vermaas (2010, pp. 34–37), which additionally features a recursive break-down of the artefact into its components. There are also clear parallels to (Galle, 1999), in which 'designing' is defined as 'the production of a design representation' (an artefact proposal in our current terminology), after which a comprehensive definition of 'design representation' is developed.

For the present purposes, however, there is no need to go further into the technicalities of the various definitions of 'design' in the theoretical literature. Suffice it to conclude at this point that the conception of design we have proposed is by no means unrelated to what has been developed by various design theorists. There may not be consensus among theorists about the details, the phrasing, or the technique of defining; but on the whole the overall notion of design as an act of expressing a novel idea of an artefact in order to plan, prepare or enable the making or production of such an artefact seems to have considerable currency.

Yet the critical reader may question the plausibility of our conception of design by asking if the 'novel idea of an artefact' to which we appeal is not in *itself* an artefact – and worse: an artefact that must itself have been *designed* (in order to fulfil the non-trivial purpose we accord it in our definitions)? If so, that idea would depend on a second idea, according to which it had been made; that second (designed) idea would again have been made according to yet a third (designed) idea, and so forth *ad infinitum*. In short, our conception of

design is highly *im*-plausible, because on a closer inspection our definition presupposes the very concept of design itself, and involves an infinite regress as well.

Confronted with such criticism, we reply that nothing in our approach assumes or implies that ideas are artefacts and that given the rather radical nature of the claim that ideas are artefacts the burden of proof for this claim rests on those who put forth the above criticism. Ideas, we submit, are not entities we ‘make’ or produce, at least not in the same way we make or produce (abstract or concrete) artefacts and therefore, they are not themselves designed. The means by which people *express* ideas – poems, novels, artefact proposals,<sup>11</sup> or indeed scientific theories (as they manifest themselves in lectures and publications, for example) – are artefacts, for they are intentionally made or produced for a purpose (Hilpinen’s defining characteristics of artefacts).<sup>12</sup> The ideas themselves, however, may be conceived of as mental states, and as such may be acquired cognitively or through perception. We can acquire, remember and forget them, but we do not ‘make’ them any more than we ‘make’ other mental states; say, of confidence, confusion, mirth, love, or whatever. Alternatively, ideas may be conceived of as abstract entities, that we merely ‘access’ or become aware of cognitively, but on such a conception, it makes even less sense to think of them as something we ‘make’.

Nor does Hilpinen’s concept of *artefact*, as he himself analyses it, seem to include ideas. He acknowledges that artefacts ‘form an ontologically heterogeneous collection of entities which extends across the traditional philosophical boundaries between concreta and abstracta, and substantial objects, events, and processes’ (2011, Section 6). The abstract entities include what he calls ‘types’ or ‘type objects’ (Section 2), but he seems to distinguish between artefacts (whether abstract or concrete) and what he calls the ‘productive intention’ of the ‘author’ (i.e., maker or producer) of an artefact. Artefacts depend for their ‘existence and some of their properties’ on their author’s (or multiple authors’) productive intention. But nowhere does Hilpinen seem to describe such productive intention itself as an artefact. ‘The causal tie between an artefact and [...] its author’s productive intention’ he explains, ‘is constituted by an author’s actions, that is, by his work on the object’ (Section 4). So Hilpinen’s notion of an artefact-author’s productive intention is very similar to our notion of a designer’s ‘idea for an artefact’. Even though Hilpinen is not concerned with *design* as such, he remarks (Section 4, further on) that the ‘productive intention is often expressed by cognitive artifacts which show the character of the intended artefact and the way it should be constructed, for example, a drawing, a diagram, or a model [...]’. What he calls ‘cognitive artifacts’ (the drawings etc.), are precisely what we have called ‘artefact proposals’. (Contrary to Hilpinen, however, we will argue in Section 3.5 below that artefact proposals are not primarily *cognitive* artefacts.) Hilpinen is mostly concerned with what might be called *direct production* of artefacts

based on a ‘productive intention’, while we are concerned with the more *indirect production* that involves design; i.e. an initial production of an artefact proposal which, in turn, enables the designer or some other agent to produce the final artefact.<sup>13</sup> Thus the theory of design inherent in the definitions we have proposed may be seen as an extension of Hilpinen’s theory of artefacts (apart from minor differences in terminology).

To sum up, our conception of design is ‘plausible’ in the sense that, as we have shown, it is compatible with ordinary parlance, it is rooted in several related analyses of the design concept from the theoretical literature, and it constitutes a rather seamless extension of Hilpinen’s theory of artefacts. What remains of Farrell & Hooker’s challenge, is to ‘provide explicit arguments’ to show that it ‘does not include science’. But first we should state explicitly how we intend to use the other key term of the comparison, ‘science’.

### 3.3 *An analogous conception of science*

According to our definitions so far, what a designer does in order to *design* is, essentially, to produce an *artefact proposal*; that is, a representation of some novel artefact-idea with the purpose of enabling the designer or someone else to make one or more artefacts according to that idea. To ‘do science’<sup>14</sup> may be thought of (quite analogously) as performing another kind of intelligent action, namely science. For the purposes of the present paper, we shall assume that the following definitions apply (compare the definitions of ‘design’ and related terms in Section 3.1.):

‘*Science*’ (noun, uncountable): the kind of intelligent action that consists of forming a novel, non-trivial, and well-supported belief about some part of the world (e.g., natural, artificial, social<sup>3</sup>), for the purpose of better understanding. (The belief is to be *novel* in the sense that it is about a discovery of new facts, new predictions or new explanations of facts previously described.)

The result of expressing the belief formed by such an action we call a ‘*scientific theory*’ (under which we include an observation report as a degenerate case),<sup>15</sup> and the countable noun ‘*scientist*’ will be taken to mean: an agent, who performs an act which is an instance of science as defined above.

Without going into details about the nature of science or the scientific ethos (which would require a lengthy analysis, e.g. of the notion of ‘well-supported belief’), we believe that this brief sketch accords with the views on science that Farrell & Hooker express, and that the general conception of science that it suggests is just as plausible as is our conception of design. For example, one meaning of ‘science’, according to the afore-mentioned corpus-based dictionary ([Longman Dictionary of Contemporary English](#)), is ‘the study of knowledge about the world, especially based on examining, testing, and proving facts’.

Furthermore, by defining ‘science’ in close analogy to ‘design’, we seek to establish some common conceptual ground with Farrell & Hooker. It might have been possible to conceive more polemically of ‘science’ so as to render its meaning completely unrelated *by definition* to the meaning of ‘design’, thereby ‘defeating’ Farrell & Hooker’s thesis of unification. But that would have missed the whole point of the present discussion. As stated earlier, our objective is not to prove Farrell & Hooker wrong, but to clarify (and, of course, justify) whatever differences *and* similarities we see between (plausible conceptions of) science and design.

The idea of comparing, and distinguishing, science and design while acknowledging a certain analogy between them, is not new. Elaborating on insights originally presented in (Roozenburg & Eekels, 1995, Section 5.5), Roozenburg (2002) does precisely that. His point of departure, however, is not a pair of definitions, but an analysis of design and ‘empirical scientific inquiry’ in terms of ‘the empirical cycle’, a notion taken from de Groot’s psychological theory of problem solving. This enables Roozenburg to visualize an analogy very convincingly, by two structurally identical flowcharts of the problem solving processes that constitute empirical science and design. He compares each pair of analogous sub-processes in turn, finding significant differences, e.g. regarding the desired kind of result, methods used, and criteria for evaluating results. Summing up his comparison, he observes that ‘design and research in modern science and technology [...] mutually support each other, but to a large extent due to their differences’.

As will soon become clear, we tend to agree with Roozenburg’s conclusions, but our theoretical point of departure is different: We aspire to cover a more general conception of science than that of *empirical* research alone. And as for empirical research, we do not wish to commit ourselves, as Roozenburg does, to the view that it involves *observation* and *induction* as essential steps – a view that was vigorously challenged by Popper (e.g., see Popper, 1989, pp. 46, 53).

### 3.4 *Why science is not design*

A scientific theory, although it may itself be considered an artefact, does not in general represent or express an idea *of* an artefact so as to enable anyone to make an instance of that artefact. Here, we think, lies the crux of what makes science different from design. (Admittedly, under special circumstances, as in cases of ‘applied’ or technological research, a scientific theory may be an essential prerequisite for making an artefact proposal – say, for a new type of medicine, or a new kind of fighter plane – but that does not make the theory itself an artefact proposal.) Therefore, science, as defined above, is simply not subsumed under design, as we have conceived of it. (Which is not to say that scientists never design, in their capacity as professionals. No doubt they often do.

For example, they may design methodical procedures or scientific instruments for their research, as Farrell & Hooker point out.)

What a scientist must do in order to ‘do science’ is, as we contended, essentially to produce *a scientific theory* (be it with or without co-occurrence of design). By contrast, what a designer must do, essentially, in order to *design* is *not* to make what would be analogous to the scientist’s theory: namely a *designed artefact*. (For an architect, for example, such a designed artefact would usually be a building or some part of a city; for a fashion designer it would be a collection of clothes; for a mechanical engineer, a machine or some other mechanical device; for a graphic designer it might be a logo or a typeface; and so forth.) In general, for a designer to design it is sufficient that he proposes a novel idea as specified in our definition. But the definition does not require that actually any (final) artefact be made according to that idea. All it requires is that proposing the idea *enables* the designer or someone else (say, a contractor or a manufacturer) to make such an artefact (possibly after further designing concerning various details etc. but that is not essential).

More generally: following a particular act of design, one or more designed artefacts *may* be made according to the artefact proposal resulting from that act; but no making of artefacts according to artefact proposals *must* take place for an act of design to have occurred. A student of architecture, for example, who does a successful studio project as part of his architectural training, *designs* according to our definition, even though no building is ever built as a result. Even Jørn Utzon designed in vain as it were, when in 1953 he made a non-winning entry for an architectural competition for a restaurant at the harbour front of Copenhagen (Weston, 2008, pp. 48–55).

So, after completing an act of ‘doing science’, the scientist must have produced an artefact of the kind that is the *raison d’être* of science: a scientific theory. But after completing an act of design, the designer may have produced a mere *proposal* for an artefact of the kind that is the *raison d’être* of design. (Or even, perhaps, just have thought of it: ‘proposing’ the artefact mentally.) That, too, is a reason why science is not design; indeed why design, in Farrell & Hooker’s turn of phrase, ‘does not include science’.

### 3.5 *In defence of the traditional distinction argument*

We shall now argue that even though Farrell & Hooker are right that both science and design produce *artefacts*, those artefacts are nevertheless so significantly different that it is justified to claim that science and design ‘produce metaphysically distinct kinds of things’, as premise 2 of the traditional distinction argument has it (Table 2).

A first point to be noted is that science as a social phenomenon produces several, very different kinds of artefacts (experimental equipment, journals,

prizes, unions, scientific institutions, etc.), but here we will focus on the artefacts that are distinctive for science conceived of as a *kind of* intelligent, cognitive *action* (see our Section 1.3), namely *scientific theories*. The other artefacts may be considered outcomes of actions that co-occur with the practices of ‘doing science’.

A *scientific theory* is the immediate and essential output of an act of scientific research. In that respect, the theory may be considered the scientific counterpart of an *artefact proposal*, which is the immediate and essential output of an act of design. Now a theory may be characterized as a ‘cognitive artefact’, to use Hilpinen’s term: it is intentionally made for purposes of expressing the results of cognition. However, it would be rather misleading to characterize an artefact proposal as a cognitive artefact since it serves primarily a practical purpose, namely to make it possible to produce an instance of the proposed artefact (the function of the proposed artefact may be one to support cognitive action by humans; for instance, the function of a calculator is to support users in making calculations; but that does not make the artefact proposal itself a cognitive artefact). For that purpose the artefact proposal contains a description of all the relevant features that must be realized when making such an instance. Thus, an artefact proposal may better be characterized as a (symbolic) *practical artefact* instead of as a cognitive artefact: under certain conditions (relevant skills, materials etc.) it allows someone to do certain things, just as, for instance, a hammer or a bicycle does, but in contrast to a hammer or bicycle the artefact proposal has primarily a symbolic character. This symbolic character it has in common with cognitive artefacts. But a scientific theory and an artefact proposal are different kinds of artefacts. A theory is a *cognitive-descriptive* artefact, whereas an artefact proposal is a *practical-prescriptive* artefact.

To clarify this difference, consider the following thought experiment. A designer has designed a totally new kind of artefact, called a ‘turbo-shaver’. The artefact proposal for the turbo-shaver, which is itself an artefact, contains all kinds of details about its overall function and of the structural features of all of its parts. On the basis of this artefact proposal an actual instance of the new kind of artefact has been produced and tested satisfactorily, and mass-production of turbo-shavers has begun.

Then a scientist comes along who is interested in studying the new kind of artefact, but he is not allowed access to the artefact proposal. He studies the physical features of an actual turbo-shaver and by reverse engineering, or by flattery and clever questioning of its designer, tries to determine its overall function and the structural features of its parts. Now suppose the scientist gets all things right and produces a complete description of the turbo-shaver, a report that content-wise is indistinguishable from the designer’s artefact proposal. Nevertheless, the scientist has not designed the turbo-shaver!

There is a crucial difference between the (symbolic) artefacts produced by the designer and the scientist. With regard to the designer's artefact proposal, it did not make sense to ask upon its completion, whether it was true or not, whereas this does make sense for the scientist's report. The report is a (true or false) description (representation) of an actually existing object (or collection of objects). In other words, as a cognitive artefact, it is purely *descriptive*. The artefact proposal, on the other hand, may be taken to be the *definition* of a new kind of artefact that, if accorded a truth-value at all, was true by *stipulation*. From the point of view of making a turbo-shaver this means that the artefact proposal functions as a *prescription*. The definition of the turbo-shaver *de facto* functions as a norm or recipe for making one; as a practical artefact the artefact proposal is *prescriptive* in nature. In order to be able to perform this prescriptive function the artefact proposal has to contain an artefact-description. But that does not make it a cognitive artefact in the same way a scientific theory is a cognitive artefact.

In this respect it is interesting to point out an ambiguity in Hilpinen's characterization of cognitive artefacts as ones 'which show the character of the intended artefact and *the way it should be constructed*' (Hilpinen, 2011, italics added; also quoted in our Section 3.2). So, Hilpinen's cognitive artefacts are descriptive and prescriptive at the same time. In order to avoid any confusion with cognitive artefacts that are purely descriptive, such as scientific theories, and because the descriptive element of an artefact proposal is a *conditio sine qua non* for performing its prescriptive function, we think it is better to characterize artefact proposals as practical-prescriptive artefacts.

Since designers' artefact proposals are prescriptive as just explained, they have no subject matter in the sense of some existing entities they are 'about',<sup>16</sup> in contrast to the scientists' theories (as expressed in reports, articles, lectures etc.). Despite whatever superficial similarities there may be between the symbolic artefacts produced by scientists and by designers (as illustrated by the turbo-shaver example), there is one all-important difference that sets them apart: scientists concern themselves with what exists; designers with what does not exist. Therefore we feel justified in claiming that the essential artefacts produced by science and by design are, in fact, 'metaphysically distinct types of things'. And so it makes sense, *pace* Farrell & Hooker, to claim that the second premise of the traditional distinction argument (Table 2) is true after all.

### 3.6 Methodological distinctions

The above analysis of the kinds of artefacts produced by science and design – cognitive-descriptive artefacts, and practical-prescriptive ones, respectively – suggests that there might be a similar contrast between design methodology, and the methodology of science. Let us therefore briefly address the question whether there are significant differences in the methodology of science and design as problem solving activities. Here we take methodological issues to



be primarily concerned with the ways proposed solutions to problems are evaluated and justified.

In science, various *criteria for evaluation* of proposed solutions (theories, descriptions) are in use, such as truth, empirical adequacy, explanatory power, simplicity, beauty, coherence etc. Opinions on whether all of these make sense and how they are related to each other (hierarchically or not) differ widely, but truth, in whatever way interpreted, is usually taken to be one of the most basic criteria, if not *the* most basic one. The list of criteria for evaluating artefact proposals looks very different: efficacy, efficiency, feasibility, safety, beauty, patentability, maintainability, and profitability etc. Truth does not occur on the list; it simply does not make sense to argue for the truth of an artefact proposal; it is tantamount to making a category mistake. As Kock notes, in contrast to ‘factual claims’ that are true or false, ‘*practical claims* about purposive choices’ are not: ‘it is categorically misleading to describe them as either true or false’ (2011, p. 72, emphasis original).

Note that the differences in evaluation criteria of science and design run closely parallel to our characterization of the products of science and design as respectively cognitive-descriptive and practical-prescriptive artefacts. Cognitive-descriptive artefacts, the products of science, are subjected to epistemic norms and criteria, whereas practical-prescriptive artefacts, the products of design, are subjected to practical norms and criteria. It goes without saying that this difference in norms and criteria is a direct consequence of the difference in stance (descriptive versus prescriptive) of science and design towards the world.

Whether or not this difference in stance also leads to differences in the foundations upon which *justifications* of proposed solutions are based, or to differences in the specific methods of justification in science and design, remains to be seen. Usually justification in science is analysed in terms of the inductive, the hypothetical-deductive and abductive methods. Whether these methods exhaust the methods of justification in design, or whether specific methods are employed in design, is an open matter. Often it is claimed that the methods of science are analytic and those of design synthetic, but it turns out to be rather difficult to clarify what this difference amounts to (Kroes, 2009).

Finally, trade-offs among various evaluation criteria play almost no role in science, but in so far as they do play a role it concerns trade-offs between epistemic criteria (values). In design, by contrast, trade-offs play a dominant role, and these trade-offs may involve different kinds of evaluation criteria (values); for instance, a trade-off between efficiency (technical value) and safety (moral value). Various methods have been developed to deal with such trade-offs (among which multiple criteria analysis), but again further

study has to reveal whether or not we are dealing here with a significant methodological difference between science and design.

Even so, the above considerations taken together would seem to suggest that an argument for considering science and design distinct in nature could indeed be developed from a more thorough comparison of their respective methodologies.

Apparently, this contention stands in stark opposition to what Dasgupta calls the ‘*design-as-scientific-discovery (DSD) hypothesis*’, according to which ‘[d]esign problem solving is a special instance of (and is indistinguishable from) the process of scientific discovery’ (1994, p. 210, italics original).<sup>17</sup> Commenting on his DSD, Dasgupta notes that ‘although it is mostly true that the *aims* of the natural and the artificial sciences [design] differ, one should not confuse the differences in aims for differences in *methodology*’ (*ibidem*); and that DSD, ‘if accepted as valid would signify that science [...] and engineering [design] [...] are methodologically indistinguishable’. Dasgupta furthermore conjectures, as a ‘*central hypothesis of scientific creativity*’, that ‘[t]he process of inventing artifactual forms (or creating original designs) in the artificial sciences is cognitively indistinguishable [...] from the process of inventing theories or discovering laws in the natural sciences’ (*op. cit.*, pp. 210–211, italics original).

To us, however, the similarities that Dasgupta highlights in his two hypotheses are not so much about *methodology* in our sense of the word (stressing as we do the evaluation and justification of artefact proposals and theories), as about design and science understood as kinds of *cognitive action*. For Dasgupta, methodology is about *cognition* involved in the creative processes of design and science. In the chapter from which we quoted, he is reflecting on the lessons that may be drawn from a comprehensive case study of ‘how a particular act of inventive design *might* have taken place’ (*op. cit.* p. 189, emphasis added): viz. Maurice Wilkes’ landmark invention in 1951 of microprogramming for digital computers, and a control unit architecture to support it. And to answer that question, Dasgupta uses a method of rational-computational reconstruction of Wilkes’ *thinking* (the plausibility of which as a model of actual events rests on its compatibility with historical evidence).

The opposition between our view and that of Dasgupta is only apparent. For, as we noted in Section 1.3 and at the end of Section 2.1, we do not see design as primarily a kind of *cognitive action*, although it involves such action, and we use the word ‘methodology’ differently. But to the extent that both creative invention in design and creative discovery in science *are* instances of cognitive action, we see no reason to deny the similarities that Dasgupta suggests. This is perfectly compatible with our contention that, as we have been arguing, design and science are distinct but related kinds of *intelligent action*.

## 4 Conclusion

From a very general perspective science and design may seem like identical twins or ‘as like as two peas in a pod’, as the saying goes. They may both be characterized, as Farrell & Hooker argue, as intelligent problem-solving activities that produce artefacts. But from such a perspective one may easily end up claiming that, in Popper’s words, ‘All life is problem solving’<sup>18</sup> and thus that all activities in life boil down to one kind of action. Not all problems, however, are of the same nature. As soon as we zoom in on the intelligent problem-solving activities that go on in science and design, and the means and ends involved, differences between the two kinds of activities become noticeable.

As Heylighen et al. remark (2009), the science–design distinction may be aptly described in terms of Searle’s ‘direction of fit’. What matters in science is ‘mind to world fit’: problems arise when there is somehow a misfit between our conception (theory) of the world and the world itself. In design problems are all about ‘world to mind fit’: we try to adapt the world to our ideas by making proposals for (effective and efficient) physical or abstract artefacts.

This difference does not entail that design plays no role in science and vice versa. Modern experimental science requires the design and making of often very sophisticated equipment, and design may necessitate research into phenomena, for instance human behaviour. Thus, *co-occurrence* of science and design is usually to be expected.

However, that should not be allowed to obliterate further differences between them. Distinctions between kinds of intelligent action may be made on various grounds, such as their (1) aim, (2) subject matter, (3) products, and (4) methodology. Summing up our comparison of science and design as kinds of intelligent action, we have reached the following results:

- (1) Science and design have different aims. This difference in aim may be described in various ways: to study or describe the world versus to make things or change the world; the production of knowledge (theories) versus the production of prescriptions how to act (artefact proposals).
- (2) Science and design have the same subject matter, namely the ‘world’ (see (1)) which comprises the domain of the natural and of the artificial: science studies natural and artificial phenomena; design produces proposals for artificial things. But, in order to do so, design studies (has to study) natural and artificial phenomena, too (or draws on results from science).
- (3) Science and design both produce symbolic artefacts: theories (and other products of science) are symbolic artefacts just as artefact proposals are. However, the theories of science are cognitive-descriptive, while the

artefact proposals of design are practical-prescriptive. (This, of course is related to the first point.)

- (4) Methodologically, science and design differ with regards to the criteria for evaluation of solutions to problems. Notably, truth (in some sense) is a central concern in evaluating a scientific theory, but it makes no sense to discuss the ‘truth’ of a designer’s artefact proposal. It would also appear that in design, trade-offs among such evaluation criteria play a central role, while this is not the case in science.

So, to answer the metaphorical question in the title of this paper: arguably, science and design are relatives, perhaps even siblings; they often enjoy each other’s company, but they are hardly twins, and certainly not identical twins.

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### *Notes*

1. Farrell & Hooker’s main sources of information on the conventional view are Simon’s book and a paper by Kroes (2002), to which we return shortly. In that context they also briefly cite Willem and Archer (on pp. 481 f). We have cited a slightly different sample of authors above, not only because of their succinct statements of the conventional view itself, but also because the quotes suggest arguments in its support, which we will discuss later on.
2. Between the two fragments just quoted, Farrell & Hooker also challenge proponents of a science—design distinction to ‘say just how to construe the definitions of artificial and artifact so as to make out a relevant and defensible difference.’ We assume the difference at issue is that between science and design, which is in the focal point of our paper. We will have more to say about the notion of artificial and artefact below.
3. Since the meaning of the term ‘science’ tends to be biased towards research into natural phenomena (as in physics, geology, biology etc.) which is inadequate in the present context where science covers the study of the natural *and* the artificial world, we would have preferred to use the term ‘research’ instead of ‘science’; the notion of research is more neutral with regard to the character of its object of study (that is, whether it is natural or artificial). Moreover, the term ‘research’, just as the term ‘design’, may stand for a verb and thus indicate a kind of action. However, we will stick to the use of ‘science’ since Farrell & Hooker initiated the discussion using that term.
4. As Heylighen et al. observe (2009), ‘One may have to design a research project or a series of experiments in order to obtain some results. Similarly, research may be needed for designing an artifact [...], but it is not what design is about.’
5. In this respect it is interesting to note that CERN, as one of the paramount institutions for performing scientific experiments in the field of particle physics employs many more engineers than scientists; see (Board of European Students of Technology, 2013), where under the tab ‘Detailed profile’ it says: ‘Surprisingly, only 2.5% of staff at CERN are research physicists; 33% are engineers and applied physicists, and 33% are technicians and technical engineers.’
6. This means that the idea is not necessarily novel in the more strict sense that it has not yet been proposed by anybody. Somebody who comes up with a ‘novel’ idea for an artefact, that unknown to this person has already been proposed by somebody else, is still performing an act of design. That is, in proposing the idea, the agent who does so is merely

required to exhibit what Boden calls ‘psychological creativity’; not ‘historical creativity’ (2004, pp. 2, 43 ff.).

7. For the purpose of developing a theory of design, it is unfortunate that the verb and the noun ‘design’ are identical in form. It would have been convenient if they were morphologically distinct (as in ‘compute’ and ‘computation’, say), but coping with such quirks of natural language is part of the challenge we face as theorists.
8. This dictionary is corpus-based, according to (Mondorf, 2009).
9. ‘Ontologically [Hilpinen explains], an artifact can be a singular, concrete object such as the Eiffel Tower, a type (a type object) which has or can have many instances (for example, a paper clip or Nikolai Gogol’s *Dead Souls*), an instance of a type (a particular paper clip), or an abstract object, for example, an artificial language’ (*op. cit.*, Section 2).
10. A philosopher of Platonistic persuasion might re-construct the ‘idea’ we talk about as (what is known in metaphysics as) a *universal*. So when Buchanan, as quoted in the introduction, says that ‘scientists are concerned with understanding the *universal* properties of what is, while designers are concerned with conceiving and planning a *particular* that does not yet exist’ (Buchanan, 1992, p. 17 n. 42, emphasis added), we do *not* consider that remark a basis for a distinction argument. Science and design can be distinguished, but not on the grounds that the major concerns of scientists and designers are universals and particulars, respectively.
11. The *form* or underlying system in which a complex artefact proposal is expressed, e.g. a data base for ‘product modelling’, or a standardized system of working drawings, may itself have been designed, but once it is available as a medium for expression of ideas, such expression of ideas does not in itself necessitate design.
12. In this context it is interesting to note that ideas cannot be patented; no one can be granted a monopoly on an idea, but only on expressions of ideas, that is, artefacts; see, for instance (Koepsell, 2009).
13. This roughly corresponds to a division of labour between the intellectual and physical work involved in making material artefacts. The complex process of *communication* often involved has been analysed in (Galle, 1999).
14. We resort to this colloquial expression for want of a verb that corresponds to the noun ‘science’.
15. Recall that in Section 1.4, we considered observing a solar eclipse as a primitive kind of doing science. Correspondingly, the resulting observation report would be a primitive kind of scientific theory, as defined here.
16. In this respect, they may even be thought of as belonging to a special genre of *fiction* (Galle, 2008, Section 5.3).
17. Note how this is an almost exact mirror-image of Farrell & Hooker’s thesis of unification, that science is subsumed under design: ‘both of them [i.e., design and science] are most accurately represented, cognitively, as design processes’ (2012, p. 494).
18. The title of a lecture held by Popper in Bad Homburg in 1991; available in (Popper, 1999).

## References

- Bamford, G. (1990). Design, science, and conceptual analysis architectural science and design in harmony. In *Joint ANZAScA/ADTRA Conference, Sydney, 10–12th July, 1990* (pp. 229–238).
- Board of European Students of Technology. (2013). CERN Retrieved 2013-04-27, from <http://www.best.eu.org/student/career/companyProfileView.jsp?company=dps6w2q>.
- Boden, M. (2004). *The creative Mind: Myths and mechanisms* (2nd, revised ed.). Routledge.
- Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, 8(2), 5–21.
- Buchanan, R. (1998). Branzi’s dilemma: design in contemporary culture. *Design Issues*, 14(1), 3–20.

- Buchanan, R. (2001). Design research and the new learning. *Design Issues*, 17(4), 3–23. <http://dx.doi.org/10.1162/07479360152681056>.
- Buchanan, R. (2004). Design as inquiry: the common, future and current ground of design. In *DRS Futureground International Conference, Melbourne*.
- Dasgupta, S. (1994). *Creativity in invention and design: Computational and cognitive explorations of technological originality*. Cambridge: Cambridge University Press.
- Farrell, R., & Hooker, C. (2012). The Simon—Kroes model of technical artifacts and the distinction between science and design. *Design Studies*, 33(5), 480–495. <http://dx.doi.org/10.1016/j.destud.2012.05.001>.
- Galle, P. (1999). Design as intentional action: a conceptual analysis. *Design Studies*, 20(1), 57–81. [http://dx.doi.org/10.1016/S0142-694X\(98\)00021-0](http://dx.doi.org/10.1016/S0142-694X(98)00021-0).
- Galle, P. (2008). Candidate worldviews for design theory. *Design Studies*, 29(3), 267–303. <http://dx.doi.org/10.1016/j.destud.2008.02.001>.
- Galle, P. (2011). Foundational and instrumental design theory. *Design Issues*, 27(4), 81–94. [http://dx.doi.org/10.1162/DESI\\_a\\_00107](http://dx.doi.org/10.1162/DESI_a_00107).
- Heylighen, A., Cavallin, H., & Bianchin, M. (2009). Design in mind. *Design Issues*, 25(1), 94–105. <http://dx.doi.org/10.1162/desi.2009.25.1.94>.
- Hilpinen, R. (2011). *Artifacts*. *The Stanford Encyclopedia of philosophy* (Winter 2011 ed.). from <http://plato.stanford.edu/archives/win2011/entries/artifact/>.
- Houkes, W., & Vermaas, P. E. (2010). *Technical functions. On the use and design of artefacts*. Dordrecht: Springer.
- Kock, C. E. J. (2011). Why argumentation theory should differentiate between types of claim. In J. A. Blair, & R. H. Johnson (Eds.), *Conductive argument: An overlooked type of defeasible reasoning* (pp. 61–72). King's College London: College Publications.
- Koepsell, D. (2009). *Who owns you? The corporate gold rush to patent our genes*. Oxford: Wiley-Blackwell.
- Krippendorff, K. (2007). An exploration of artificiality. *Artifact*, 1(1), 17–22. <http://dx.doi.org/10.1080/17493460600610848>.
- Kroes, P. (2002). Design methodology and the nature of technical artefacts. *Design Studies*, 23(3), 287–302. [http://dx.doi.org/10.1016/S0142-694X\(01\)00039-4](http://dx.doi.org/10.1016/S0142-694X(01)00039-4).
- Kroes, P. (2009). Foundational issues of engineering design. In A. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 513–541). Amsterdam: Elsevier.
- Kroes, P. (2012). *Technical artefacts: creations of mind and matter*. Dordrecht: Springer.
- Longman Dictionary of Contemporary English. Design. Retrieved 2013-04-07, from <http://www.ldoceonline.com/search/?q=design>.
- Longman Dictionary of Contemporary English. Science. Retrieved 2013-11-05, from <http://www.ldoceonline.com/dictionary/science>.
- Lowe, E. J. (1995). The metaphysics of abstract objects. *The Journal of Philosophy*, 92, 509–524.
- Mondorf, B. (Producer). (2009). Corpus linguistics. *English linguistics*. [Web site of Johannes Gutenberg Universität, Fachbereich Philosophie & Philologie] Retrieved from <http://www.english-linguistics.uni-mainz.de/231.php>.
- Popper, K. R. (1989). *Conjectures and refutations. The growth of scientific knowledge* (5th ed.). London: Routledge & Kegan Paul.
- Popper, K. R. (1999). *All life is problem solving*. London: Routledge.
- Roozenburg, N. F. M. (2002). A theory is not a thing. A methodological comparison of design and research. In *Proceedings of the sciences of design (March 15–16)*. Lyon, France: INSA-Lyon Scientific and Technical University.

- Roozenburg, N. F. M., & Eekels, J. (1995). *Product design: Fundamentals and methods*. Chichester: John Wiley & Sons.
- Rosen, G. (2012). *Abstract objects*. *The Stanford Encyclopedia of philosophy* (Spring 2012 ed.). from <http://plato.stanford.edu/archives/spr2012/entries/abstract-objects/>.
- Simon, H. A. (1996 [1969]). *The sciences of the artificial* (3rd ed.). Cambridge, MA: MIT Press.
- Skolimowski, H. (1966). The structure of thinking in technology. *Technology and Culture*, 7(3), 371–383.
- Weston, R. (2008). *Utzon – Inspiration, vision, architecture* (2nd ed.). Hellerup: Edition Bløndal.